

# There is no Horizon Problem

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## Abstract

It is argued that explanations for the spatial homogeneity of the early universe need not involve thermalization. Rather, a homogeneous initial condition should be expected from the empirically known validity of the Second Law of Thermodynamics together with the modern understanding of the entropy of gravitating systems.

Ever since the pioneering 1965 antenna detection by Penzias and Wilson[1] and all the way up to the recent Planck mission[2], it has been known, ever more certainly and precisely, that the CMB is highly isotropic as seen from our location in the cosmos. Since there is no good reason why such location should be privileged in any sense, for those 52 years mainstream cosmology has been interpreting this fact to indicate that the early cosmic plasma was a very homogeneous fluid.

In 1979, though, Dick and Peebles[3], the same theoreticians who had predicted Penzias and Wilson's detection, argued that such homogeneity was an enigma, given that distant regions of the last scattering surface had not had enough time to communicate. They did not however propose any idea to explain the fact.

That puzzle was addressed by Guth[4], who called it the *horizon problem*, in a famous article published two years later. Therein, a new theory called *cosmic inflation* is presented which rests on the key assumption that in the very early universe there was a mechanism which triggered an exponential expansion, *i.e.*, inflation. That would mean that the portion of space from which the presently detected CMB was emitted would correspond to such a small region before the onset of inflation that all its parts would have had time to communicate even in the short time window before inflation started. Such communication would have led to the mentioned homogeneous state by means of thermalization, solving the horizon problem.

Let us now have another look at the issue.

We know that the Second Law of Thermodynamics holds good throughout our observable universe: there is one temporal direction in which entropy increases for all reasonably closed systems we observe, from stars and giant gas clouds to steam engines and living beings. This means that entropy was ever smaller to the past, all the way back to the Big Bang. So the old question “why are there irreversible processes?” can be reduced, in the light of modern Big

Bang cosmology, to “why is the cosmic boundary condition at the Big Bang one of low entropy?”. That understanding, shifting the problem from thermodynamics proper to cosmology, is a great advance in the history and philosophy of physics, as pointed out by Price[5]. To pursue the matter any further, however, one must know what a low entropy cosmic configuration looks like.

In the systems most commonly studied in thermodynamics — gases devoid of long-range forces — collisions are the only interactions at play, giving rise to pressure in the macroscopic domain. Since collisions are repulsive, such a system tends to occupy all available space and distribute as evenly as possible. Thermal equilibrium — the state of maximum entropy — means in this case a perfectly homogeneous configuration.

That is not so, however, when other interactions come to play. Gravity for one has an attractive effect as far as matter density dominates over the cosmological constant, as is currently the case in astronomical scales, and as was the case at the time of last scattering in the scale corresponding to the present observable universe. While a gas of molecules in a box with random initial velocities spreads to fill the box they are in, a gas of stars in the same situation would contract down to a point.

In old Newtonian gravity, the above parallel would not have been fair, since the objects in question could in principle bounce elastically and go back the way they came. The process would be a reversible one, no entropy being created. However, in general relativity, the collapse of such a system would form a black hole, an irreversible process with a huge entropy increase due the hiding of information behind the hole’s event horizon. And this is exactly the crucial point: event horizons have entropy, and the gravitational clumping of matter creates them. That is known since Bekenstein’s[6] and Hawking’s[7] studies of black hole thermodynamics in the 1970’s. And that is what makes the parallel with the gas in a box justified: while non-gravitating systems increase their entropy by turning initially inhomogeneous configurations into homogeneous ones, gravitating systems, on the other hand, increase their entropy by turning initially *homogeneous* configurations into *inhomogeneous* ones. That is precisely how structure is formed in our universe.

Since we know that entropy is ever increasing, we must conclude from the above that the universe started off very homogeneous. Just like no one should be surprised to know that a particular milkshake was once separate parts of milk, ice cream and chocolate syrup, so too the isotropy of the CMB should not come as a surprise at all, much less a problem in itself: it is precisely what one should *expect* to find when looking at early cosmic times from our knowledge of gravity and thermodynamics. So this time the question “why is the cosmic boundary condition at the Big Bang one of low entropy?” can by its turn be replaced by “why is space so homogeneous at the Big Bang?”. As one can see, there is no reason to suppose that the universe started off inhomogeneous and then seek some mechanism that could have smoothed it out by thermalization. It is true that, in the presence of an inflaton field, repulsion dominates and entropy increases by evening out the lumpinesses. The point here, however, is that there is no need to postulate inflation to explain the smoothness of the last scattering surface. If inflation is needed to solve other problems, such as flatness and structure formation, that is a whole different matter.

There is surely still a lot of meaning in asking what determines the cosmic boundary conditions, and why it must be a homogeneous one. That is a tricky

question, if anything because the very existence of a cosmic time parameter, including a Big Bang on which to impose boundary conditions, is itself tied to a maximally symmetric spatial foliation, pointing to a possible consistency loop. Maybe some theory like Penrose’s Conformal Cyclic Cosmology[8] might shed some light on the problem by showing that the initial conditions are forced by something that happened before the Big Bang. In any case, the specific idea that the homogeneity of the observable universe at the time of last scattering *must* be due to a previous thermalization of an initial inhomogeneous state should be revised. A homogeneous state *might* have been so achieved if inflation did happen, but it would *also* have been there from the start had it not happened.

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